the BEET LEAFHOPPER

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This circular contains much material formerly in Farmer's Bulletin 1886, The Beet Leafhopper, by W. C. Cook, issued in 1941.

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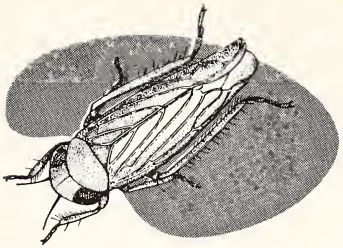

By J. R. Douglass and W. C. Cook, *entomologists, Entomology Research Branch, Agricultural Research Service*

The beet leafhopper is a serious menace to sugar beet, bean, tomato, and other crops in the West, not because of direct damage by feeding, but because it transmits curly top disease. It is the only known carrier of this disease, which attacks many important agricultural crops, ornamental plants, and weeds.

A sun-loving, dry-land insect, the leafhopper breeds in vast areas of weeds that have grown up on abandoned farmlands and deteriorated range. The misuse of land and the appearance of new weeds have created large tracts in the West which serve as breeding grounds for the leafhopper and as reservoirs of the curly top virus. When the weed hosts mature and dry, the nymphs die, and the adults that have not already moved are forced to find new food plants. They often travel long distances with the help of the wind. Generally, however, the movement is from the desert or rangeland to adjacent cultivated areas. In the course of these movements cultivated crops are infected with curly top (fig. 1).

WHAT THE BEET LEAFHOPPER LOOKS LIKE

The beet leafhopper is about ⅛ inch long, wedge-shaped, and gray to greenish yellow. In flight it appears almost white; therefore, it is widely, although incorrectly, known as the white fly. When disturbed it takes flight with a hopping motion—hence the name "leafhopper."

LIFE HISTORY AND HABITS

The beet leafhopper passes the winter in the adult stage, chiefly in uncultivated and overgrazed areas where there are mustards or other suitable host plants. The insects feed during the winter whenever the temperature permits. Most of the males die in the winter, especially in the cooler parts of the infested areas. Females are fertilized in the fall and live until spring.

Egg laying usually begins about the time the winter host plants begin their spring growth. The eggs are laid inside the tissue of the leaves and stems (fig. 2) of plants. Each female deposits between 300 and 400 eggs. The eggs hatch in 5 to 40 days, depending on the temperature. The young leafhoppers, known as nymphs (fig. 3), begin to feed immediately, inserting their beaks into the plant tissue

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FIGURE 1.—Sugar beet plant infected with curly top, showing typical curling of the leaves.

and sucking the juice. At first the nymphs are white, but in a few hours they darken considerably. As they grow they shed their skins five times, becoming larger after each molt. The older nymphs are usually spotted with red and brown. After the fifth molt they become adults and have wings (fig. 4). The adults vary in color from gray to greenish yellow, being darkest when they have developed in cool weather.

The time required for nymphal development is 3 to 6 weeks. Development from egg to adult requires 1 to 2 months.

FIGURE 2.—Eggs of the beet leafhopper embedded in the tissue of a sugar-beet leaf. Enlarged.

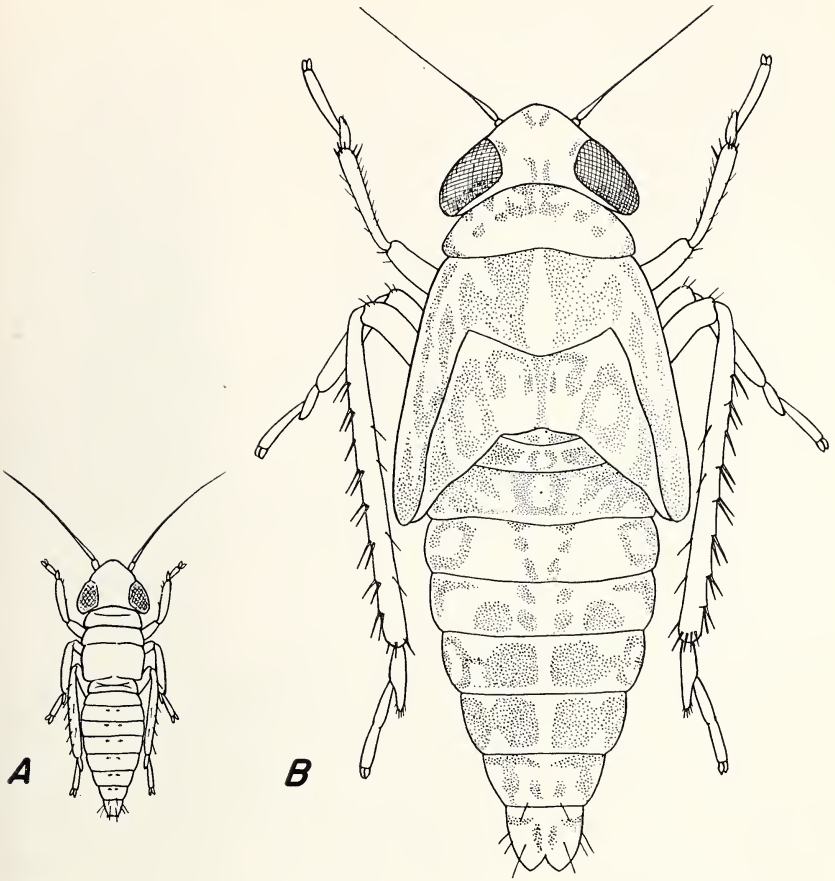

FIGURE 3.—Nymphs of the beet leafhopper: *A*, First instar; *B*, fifth instar. Enlarged.

The beet leafhopper breeds continuously during the warm months, and nymphs may be found at any time during the growing season. The generations overlap, and in the summer all stages may be found in the same breeding area at the same time. In the central Columbia River sections of Oregon and Washington, on the Snake River plains of southern Idaho, in northern Nevada and Utah, and western Colorado, three generations are produced each season. In California, southern Nevada, southern Utah, Arizona, New Mexico, and Texas, five or more generations may develop. The major breeding areas are shown in figure 5.

The first, or spring, generation is produced on weeds—chiefly mustards—which are rather short lived and usually mature and dry about the time the leafhopper reaches the adult, or winged, stage. When the weather is favorable for flight, the leafhoppers move to summer hosts, chiefly Russian-thistle. They travel with the wind and infest practically all host plants in their path.

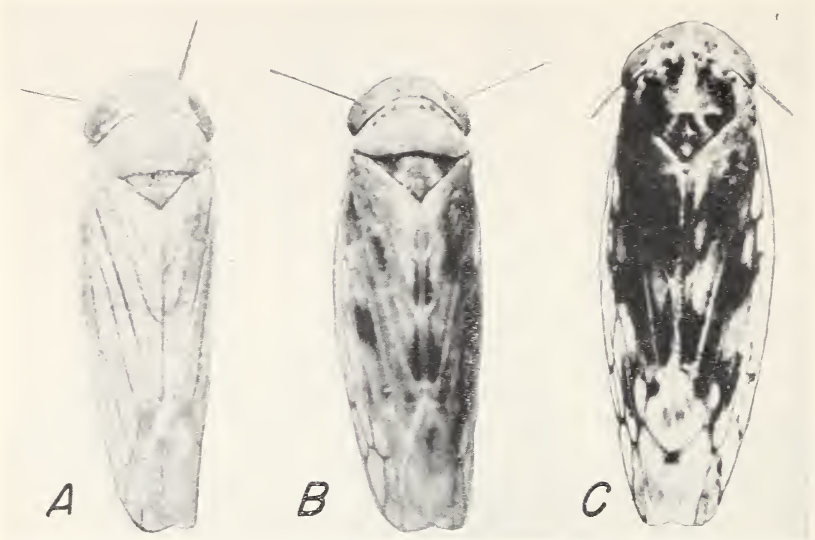

FIGURE 4.—Adults of the beet leafhopper in different seasons of the year: *A*, Summer, or light, form; *B*, spring, or intermediate, form; *C*, winter, or dark, form. All enlarged.

HOW THE BEET LEAFHOPPER SPREADS CURLY TOP

The infestation of crops is incidental to the general movements of the leafhoppers. They do not seek out a particular crop, but infest any favorable plant in their path. When moving into cultivated areas they alight in the nearest fields. Gradually they move farther into the cultivated lands. As a consequence, susceptible crops nearest the breeding grounds are most heavily infested, and thus most seriously affected by curly top. Beets are the only important breeding host among the cultivated plants. Spinach and Swiss chard are less favored. During the spring migration the leafhoppers feed on beans, cantaloups, squash, tomatoes, and other crops, but do not reproduce on them. It is during such feeding that they infect these plants with the curly top virus.

The virus of curly top survives the winter both in the beet leafhopper and in some of its winter host plants. The percentage of spring-generation leafhoppers carrying the virus into cultivated areas has varied from 4 to 80 percent. Those not carrying the virus soon pick it up from plants infected by the carriers. An infected leafhopper can infect a healthy plant in 1 minute. A noninfected leafhopper can pick up the virus from a diseased plant as quickly, but an incubation period of about 4 hours is necessary before it can transfer the virus to a healthy plant. A leafhopper infected with the curly top virus remains infective. However, it cannot transmit the virus through the egg to its progeny.

The severity of curly top epidemics depends on the magnitude and time of the movement of spring-generation leafhoppers, the percentage of leafhoppers carrying the virus, the strain of the virus, the size and condition of susceptible plants at the time of infection, and the weather.

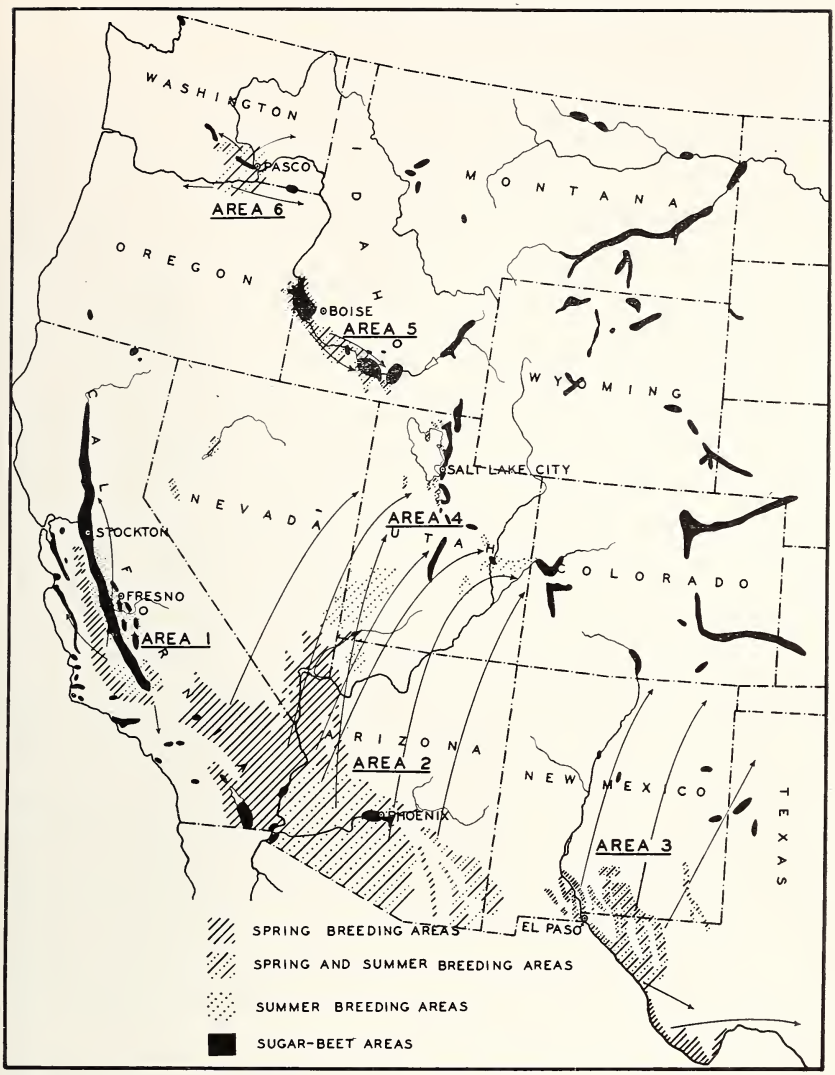

FIGURE 5.—Major breeding areas of the beet leafhopper and sugar-beet areas affected by them. Arrows indicate the general direction of spring movements of the insect.

HOW TO RECOGNIZE CURLY TOP DISEASE

Curly top is known to occur on members of at least 25 families of plants. The length of the incubation period and the severity of the disease that develops depend upon the age and condition of the plant and its resistance and the virulence of the virus. High temperature, low relative humidity, and high light intensity also increase the severity of the disease and the rate of development. Of 12 known strains, some are more virulent than others. Plants infected with

curly top show different symptoms, depending on the strain of virus, and also the plant.

In **beets** the first symptoms are the clearing of the tiny veinlets and the inward rolling of the lower and outer margins of the youngest leaves. As the severity of the disease increases, so does the curling and distortion of the leaves (see p. 2). The veins swell, and numerous wart-like protuberances, or papillae, appear on the underside of the leaves. A general stunting occurs, often ending in the death of the plant. The diseased leaves are dark, dull green, thick, and brittle. The roots show marked symptoms. The disease kills the lateral rootlets, and the beet then sends out a large number of new laterals having a hairy or woolly appearance. A cross section of diseased root often shows dark concentric rings alternating with light circular areas. A longitudinal section shows the dark discolorations extending lengthwise throughout the beet.

In **beans** the first symptoms are most pronounced on the trifoliate leaves. They become slightly puckered, curl downward, turn yellow, and die. Both these and the primary leaves are thicker than normal, are brittle, and break off readily. Young plants that are affected soon die. Plants infected late in the season do not always develop typical symptoms and usually grow to maturity, but some may drop their blossoms, become chlorotic, and die. Infected plants are dwarfed and have short internodes, giving a bunchy appearance.

In **tomatoes** the first reliable symptom is a general drooping, but not wilting, accompanied by yellowing of the young leaves and purpling of the veins. The leaves thicken and become leathery and brittle. The entire plant turns yellow and usually dies. In seriously diseased plants the blossoms may drop without setting fruit. Fruits already formed turn yellowish red, ripen prematurely, and are stunted and of poor quality.

In **squash,** symptoms are similar to those in other susceptible crops. Young seedlings that are infected as soon as they emerge from the soil may die before the true leaves appear. In the older infected plants new growth is stunted, internodes are shortened, and the leaves may roll upward at the margins. An upward bending of the tip of the runner is characteristic. Blossoms may drop and not set fruit, and the fruits already formed are stunted. There are no color differences by which a diseased plant may be identified. Wilting is not characteristic of curly top infection in squash.

Cantaloups show no reliable symptoms. Infected seedlings become severly stunted and usually die. In older infected plants new growth is stunted, internodes are shortened toward the ends of the runners, and the leaves may become puckered with the margins turned down. The flowers may be dwarfed and become dry before the petals expand. Yellowing of the plant occurs in severe cases.

Affected **spinach** is stunted, and shows crinkling and curling of the leaves, which acquire a leathery texture. In severe cases the leaves become yellowed.

In **peppers** the plants are stunted, and the leaves become thick, leathery, and roll inward. Fruits are absent or stunted and malformed. The new growth appears to be clustered at the top of the plants, giving them a rosette effect.

ECONOMIC SIGNIFICANCE OF CURLY TOP

Curly top disease limited the production of sugar beets in the West for many years. Until about 1935 the sugar-beet industry presented a drab picture of idle factories, unemployment, decreased sales, unharvested beet fields, disappointment, and waste of human effort, unpaid debts, and farm foreclosures. Eighty sugar-beet factories were established between 1897 and 1920, but 36 had been dismantled by 1940. Some factories operated only a few days in a season because thousands of acres of beets were infected with curly top and unfit to harvest. The records of southern Idaho indicate that in 1924, during a severe beet leafhopper outbreak, growers abandoned 11,442 of 22,418 acres planted to sugar beets. In 1934 they abandoned 18,635 of 21,389 acres. The average yield of the acres harvested was less than 6 tons in 1924 and less than 5 tons in 1934, as compared with a 16-ton average in years of low leafhopper exposure. Factories were dismantled and moved to other places, only to be dismantled and moved again when it was found that they had been relocated in leafhopper-infested areas.

The development of resistant varieties has made it profitable to grow sugar beets again in areas of the West that are infested with beet leafhoppers. Even these resistant varieties are susceptible to curly top in the early stages of growth; however, they are far more resistant than the varieties previously grown. The threat of failure of the beet crop has been greatly lessened, but curly top has not vanished. Serious losses have been experienced in California, Idaho, Nevada, Oregon, and Utah in recent years when large spring movements of the beet leafhopper have occurred at a time when plants were in the susceptible seedling stage. Losses were local, but dealt hard blows to growers in affected areas.

Breeding of tomatoes for resistance to curly top has been carried on for several years by the former Bureau of Plant Industry, Soils, and Agricultural Engineering and by several State agricultural experiment stations, but no varieties showing satisfactory resistance have been found. Many young tomato plants are killed outright, whereas older affected plants die gradually. In years of high beet leafhopper infestation practically the entire crop is lost. Because of the severe injury caused by curly top, no tomatoes are grown commercially in southwestern Idaho, eastern Oregon, and possibly other areas.

Most garden or snap-bean varieties are more or less susceptible. Some of the most popular varieties are the most susceptible. Such varieties are killed if they are infected when in the "crookneck," or seedling, stage. Severely infected plants are dwarfed and unproductive. Late infection hastens maturity and prevents proper development of the crop. In years when large spring movements of the leafhopper have occurred when the plants were in the seedling stage, many fields of the most susceptible varieties have been so seriously damaged in southern Idaho that it has been necessary to plow them under. Snap beans cannot be successfully grown for seed in southwestern Idaho or eastern Oregon, or in parts of the central Columbia River area of Oregon and Washington. Serious losses have occurred in most varieties of field or dry beans.

Winter-squash varieties differ in their susceptibility to curly top. Hubbard, Banana, and Golden Delicious are susceptible. Summer

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varieties also differ in degree of resistance. The Sweet Potato and Table Queen of the Fordhook group, Bush Scallop of the Patty Pan group, and Giant Crookneck and Giant Straightneck of the Crookneck-Straightneck group are extremely susceptible.

Garden beets, Swiss chard, and mangels are very susceptible to curly top. When infected in the seedling stage the plants are severely injured or killed.

Cucumbers, cantaloups, and watermelons are less severely affected than some of the other plants. If the seedlings are infected, they may die. The growth at the tips of the runners is checked and the entire plant weakened. The quality of the fruit is also impaired. Because of the prevalence of curly top the growing of cucumbers and melons has had to be discontinued in some areas otherwise highly adapted to their culture.

Young spinach plants are readily killed by curly top, and older plants are stunted. In the northern range of the leafhoppers spring spinach is often affected: in the southern areas the fall crop suffers. In southwestern Idaho spinach cannot be grown profitably for commercial processing.

CONTROL OF THE BEET LEAFHOPPER

Control of the beet leafhopper is difficult, because the damage is caused by the curly top virus rather than by the feeding of the insect, and even a short feeding will cause virus infection. Over a long period of time, rehabilitation of the desert ranges and substitution of nonhost for host plants will eliminate the breeding areas. This rehabilitation requires thorough understanding of the plant ecology of these areas as well as the habits and host plants of the insect. Spraying the breeding grounds when the leafhoppers are concentrated there will reduce the numbers reaching the cultivated areas. After they move into susceptible crops, there is no entirely satisfactory control. The planting of resistant varieties, the proper timing of planting, and treatment with insecticides will aid in reducing crop damage.

Elimination of Breeding Areas

Weed hosts of the beet leafhopper become established on abandoned, burned, idle, waste, and deteriorated rangelands. By replacing these weed hosts with nonhost grasses, breeding areas can be eliminated and leafhoppers brought under control.

Russian-thistle is the most important summer host of the beet leafhopper in most of its range, since from 2 to 4 generations may be produced on it. With the drying of the summer hosts the leafhoppers move to the winter-spring hosts, such as mustards, desert plantain, and filaree. Mixed stands of Russian-thistle and mustards are the most important combination of weed hosts, since the leafhoppers can overwinter and reproduce their spring and summer generations in the same area.

Perennial grasses and shrubs were the original plant cover on much of the land infested with beet leafhoppers. In the intermountain region, west and southwest, bunch grass and other forage plants are intermingled. A large part of southern Arizona, New Mexico, Ne-

vada, Utah, and southwestern Texas is covered with creosote bush, saltbush, or mesquite, intermixed with grass and other plants suitable for forage. When the original plant cover is destroyed, a succession of plants take possession of the soil. First come the annual weeds, which have little forage value. They are followed by annual grasses. Then, if there is no further disturbance, native perennial grasses and shrubs return. On abandoned fields Russian-thistle is commonly the first to appear in the succession of plant cover, followed by the mustards and by downy chess, a nonhost annual grass. On burned and overgrazed areas mustards are generally first, and then downy chess, but with further disturbance Russian-thistle appears. The succession from mustards and Russian-thistle to downy chess and then back to the weeds may continue in an endless cycle, depending on the weather and other disturbing factors.

In the King Hill area in Idaho, 185,000 acres of rangeland were surveyed in 1949, 1950, and 1951. The total acreage of Russian-thistle was 56,429 in 1949, 11,603 in 1950, and 29,901 in 1951. This shows that the weed-host areas are constantly changing. The extent of other weed areas and the distribution of the weeds have been determined by surveys.

The problem has been to replace weed hosts with nonhost perennial grasses such as crested wheatgrass. As a result of studies made by various Federal and State agencies, certain practices have been instituted and are now accepted range-rehabilitation practices.

The replacement of weed hosts is a long-term undertaking, and may best be accomplished by reseeding abandoned and burned areas. Lands should be reseeded soon after abandonment in order to decrease the competition with annual grasses and weeds for soil moisture, and to prevent wind and water erosion. The Bureau of Land Management, U. S. Department of the Interior, has done a good job of reseeding some of the burned areas in southern Idaho, as shown in figure 6. Newly seeded areas must be protected until the stand is established. If native perennial grasses are still present, prevention of grazing will accomplish the same purpose. Once a good cover is established, proper range management is needed to maintain the cover and prevent new weed-host areas from appearing.

Most range fires have their origin where downy chess forms the plant cover or has entered deteriorated sagebrush areas (fig. 7) to such an extent that it will carry fires. When downy chess matures and dries in the early summer, it becomes highly inflammable. During the fire season it is the greatest range fire hazard in the intermountain region. If this annual grass is burned under favorable conditions, it may reseed itself and again form the cover, but if there is much wind erosion or trampling by livestock, weeds may appear. Since perennial grasses remain green late in the season, they constitute less of a fire hazard (fig. 8).

The control of annual weeds on idle and waste lands in and adjoining cultivated areas is a difficult phase of land management, as these lands are subject to constant grazing and trampling by livestock and to misuse by man. In such areas control with herbicides is the most practical, provided sufficient grasses are present to prevent wind erosion.

FIGURE 6.—Crested wheatgrass planted on burned rangeland.

Spraying Breeding Grounds

In California the concentration of leafhoppers on small or accessible desert areas of Russian-thistle and perennial plants during the fall makes it feasible to kill large numbers in the foothill breeding areas by spraying.

Such a program of leafhopper control in the foothills was begun in 1931 by two sugar companies and continued by them until 1943, when the California Department of Agriculture took over the program. The program has been so effective that the growing of tomatoes and other susceptible crops has been extended into many areas formerly not suitable because of curly top.

In October 1951, following a succession of dry years that were favorable for both the beet leafhopper and Russian-thistle, an emergency arose that required the spraying of 150,000 acres of thistle. One pound of DDT was used per acre in 2 gallons of oil. The spray was applied by airplane flown at a 25-foot elevation to cover a 100-foot swath. The State spent about one-third of a million dollars to control the beet leafhopper so that susceptible agricultural crops could be grown on high-priced irrigated lands. This amount was less than one-half of 1 percent of the average annual return to the growers.

Since 1931 the control program has been successful in protecting susceptible crops in the Sacramento Valley from long-distance migrations of the beet leafhopper, and very little damage has been done to susceptible crops in the San Joaquin Valley.

In 1949 a research project was undertaken by the Bureau of Entomology and Plant Quarantine in cooperation with the Idaho Agricultural Experiment Station, bean seedsmen, growers, and stockmen to

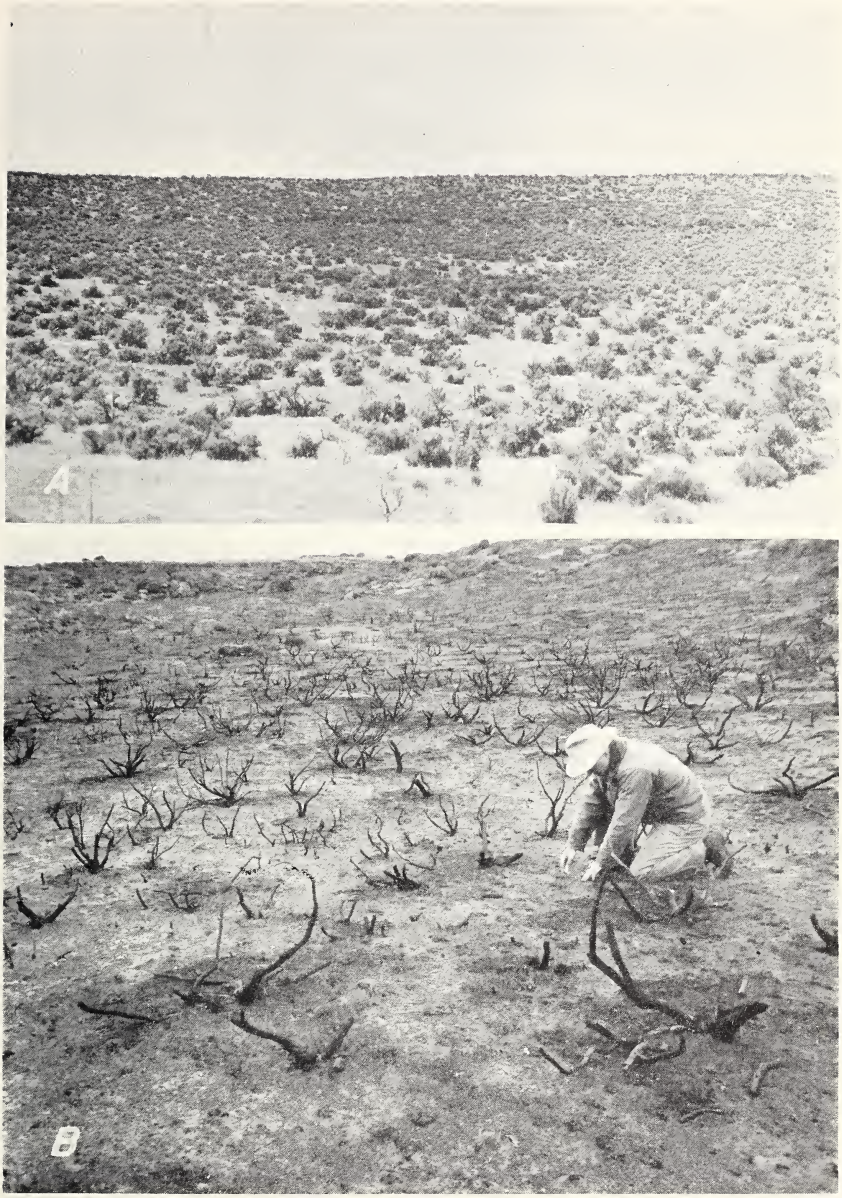

FIGURE 7.—A, Stand of downy chess in sagebrush. *B*. Sagebrush area after a fire. (Courtesy Bureau of Land Management.)

FIGURE 8.—A crested wheatgrass planting that did not burn in a downy chess fire. (Courtesy Oregon State College.)

develop methods for controlling the beet leafhopper on its weed hosts growing in uncultivated lands, desert, or deteriorated rangelands. More than three-fourths of the land studied was owned by the Federal Government, 7 percent by the State, and 15 percent by individuals. The principal object was to determine whether the seed crop of snap beans grown in south-central Idaho could be protected from curly top by destroying the leafhoppers on their spring breeding grounds.

The movement of the spring generation into the cultivated areas of south-central Idaho begins about May 24 and reaches its peak by June 22. Since the growing season is only about 128 days, the planting dates cannot be delayed until after the spring movement. The beans are usually in the "crookneck" or seedling stage, their most susceptible period when the leafhoppers move into the fields. Curly top is severe only in years when large numbers of leafhoppers invade the bean fields at the critical period for infection.

Population studies supplemented by field observations showed that overwintered females concentrate in large numbers in certain spring breeding areas. The acreage of these areas is small compared with the acreage of susceptible crops grown on irrigated lands. By taking advantage of this tendency of the leafhoppers to concentrate, it is necessary to spray only a comparatively small acreage in order to reduce leafhopper populations below injurious numbers.

There are two periods in the spring when the leafhoppers can be controlled in their desert breeding areas. The first is before the overwintered females have laid many eggs. At this time the population of leafhoppers is at the lowest point in the year. The second period is after most of the eggs have hatched. The nymphs are more susceptible to DDT than are the adults, so less is needed for effective control.

Practical control methods were developed, which consisted in applying DDT emulsion sprays with turbine blowers equipped with side-

CORRECTION

U. S. Dept. Agr. Cir. 942, The Beet Leafhopper

Page 13, under "Planting Resistant Varieties," the first sentence of the third paragraph should read "Dry bean varieties resistant to curly top are Pink, Red Mexican, Great Northern U. I. Nos. 16 and 31, and Pinto U. I. Nos. 72, 78 and 111."

delivery nozzles. The blowers were mounted on four-wheel-drive trucks, which could be driven over most of the breeding areas. The regulating devices were placed in the cab of the truck so that the driver could operate the blower. The hydraulic pump on the blower was operated at a pressure of 125 pounds per square inch and delivered 3 gallons of spray per minute. The throttle of the truck was set at a speed to deliver 2 gallons per acre over a 100-foot swath, so that 50 acres could be sprayed on one filling of the spray tank. The emulsion concentrate was prepared at the Twin Falls, Idaho, field station and trucked to the spray areas in 50-gallon drums. The water for the sprays was trucked from the nearest source in 500-gallon tanks. Approximately 15,000 acres of heavily infested wild mustards were sprayed in 1950. The spray was applied in April and May at ½ to ¾ pound of DDT per acre. The average population of beet leafhoppers was 32.9 per square foot, and the average reduction was 94 percent at a cost of 89 cents per acre.

Factors affecting beet leafhopper abundance and curly top incidence in south-central Idaho were studied, and index figures of expected infection in beans were established. Basic data showed a high population of overwintered leafhoppers, and weed-host plants and weather conditions were favorable for a severe outbreak. By calculations from these figures the curly top infection in garden seed beans and Great Northern U. I. No. 123 beans should have been 16.4 and 11.7 percent, but the recorded infections were 9.6 and 3.6 percent.

Planting Resistant Varieties

The development and planting of varieties resistant to curly top have greatly lessened crop losses.

The first resistant variety of sugar beets, U. S. 1, was developed by the Bureau of Plant Industry and released for the use of growers in 1934. Since then several resistant varieties have been developed in cooperation with various beet-sugar companies, each variety representing an improvement in curly top resistance and adaptation. These varieties are being widely planted, and their use has greatly reduced losses from curly top.

Dry bean varieties resistant to curly top are Pink, Red Mexican U. I. Nos. 16 and 31, and Pinto U. I. Nos. 72, 78, and 111. Pioneer, a small white bean that can be used either as a snap or as a dried bean, is resistant to curly top. Of the snap beans, Burpee Stringless Green Pod, Idaho Refugee, and Landreth Stringless Green Pod can be grown under moderate leafhopper infestation without danger of severe loss.

The varieties of squash and pumpkins that can be grown without serious losses from curly top are the Marbleheads, Big Tom, Golden Oblong, Southern Field, Kentucky Field, Calhoun, Large Cheese, Tennessee Sweet Potato, and various varieties of the Cushaw group.

Proper Timing of Planting Dates

Sugar beets.—In the Sacramento Valley of California early planted sugar beets almost always escape serious curly top damage. In this area, therefore, it has been the practice to plant most of the beets in January and February. Formerly the later plantings were badly dam-

aged by curly top, but the use of resistant varieties of beets and the control of the leafhopper in the desert have made March and April plantings relatively safe. In the coastal area of California beets planted after the spring leafhopper movements will make a successful crop. This practice is safe only where summer breeding of the beet leafhopper is not important. In most areas late broods of leafhoppers will cause damage. In other parts of the West early plantings are not always practical because of factors other than curly top, but experience has shown that early planted beets are less affected by curly top than are later planted ones.

Garden beets grown for seed.—Many garden beets are grown for seed by the oldtime method of planting small roots, or stecklings, in beds late in the summer. In December and January the stecklings are transplanted into large fields, set out about 3 feet apart each way. To avoid curly top infection in the root beds it is best to grow the stecklings in localities where they will not be exposed to leafhoppers. Many small areas have been found that are suitable for these plantings.

Tomatoes.—Tomato fields planted before the first spring migration of beet leafhoppers are most liable to curly top damage. Growers in regions of short growing seasons and growers of very early market tomatoes cannot wait; but in California and other places with a long growing season, it is advisable to delay planting until the vegetation on breeding grounds nearby has dried and the leafhoppers have left. Where the growing season is short, some protection has been attained by setting out 2 plants 6 inches apart in each hill. Another way to avoid loss is to cover the plants with cheesecloth caps until after the spring movement of leafhoppers.

Treating Crops With Insecticides

Curly top infection in beets and beans can be reduced and yields increased by the application of DDT in a spray or dust at a dosage of 1 to 2 pounds per acre. DDT gives a good immediate kill of the beet leafhoppers, and has a good residual effect. It must be applied about the time the leafhoppers enter the fields in order to protect the crop when it is the most susceptible. Following DDT applications, beets resistant to curly top have shown greater gains under severe leafhopper exposure than during years of light infestation.

For several years sugar beets grown for seed in Arizona and New Mexico have been treated with DDT during the fall movement of leafhoppers. A large acreage of beets grown for sugar in California has been similarly treated.

Natural Enemies

Many beet leafhoppers are destroyed each year by parasites and predators. Large numbers of eggs are destroyed by parasitic wasps that develop within them. The nymphs and adults are attacked by three groups of parasites—big-eyed flies (Dorilaidae), parasitic wasps (Dryinidae), and twisted-winged parasites (Strepsiptera). The flies and wasps deposit their eggs in or on the leafhopper, and the resulting larvae develop within or partly within its body. Upon reaching maturity the larvae work out of the leafhopper, and the leafhopper dies. The twisted-winged parasites develop differently. The female

remains within the body of the leafhopper during its entire life and gives birth to living young. These tiny larvae crawl away, attach themselves to the first leafhopper found, and bore into its body. They seldom become important aids in control because the chances of their finding leafhoppers in which to develop are slight, especially since the leafhoppers move about from host to host during the season.

Several predacious bugs, one being the big-eyed bug *Geocoris pallens* Stål, destroy large numbers of leafhoppers by sucking out the body juices. Spiders, lizards, and birds feed upon them. Livestock, principally sheep, consume many of the eggs in the plants that they eat.

HOST PLANTS

Since the beet leafhopper does not hibernate, but must feed when temperature permits activity, it requires a sequence of host plants. The principal winter-spring host plants are the following weeds:

African mustard (*Malcolmia africana* (L.) R. Br.).
Blistercress (*Erysimum repandum* L.).
Desert Indian-wheats (*Plantago insularis* Eastw., *fastigiata* Morris, and *erecta* Morris).
Filaree (*Erodium cicutarium* (L.) L'Her.).
Flixweed (*Descurainia sophia* (L.) Webb).
Green tansymustard (*Descurainia pinnata* spp. *filipes* (A. Gray) Detling).
Patata (*Monolepis nuttalliana* (Schult.) Greene).
Pepperweeds (*Lepidium nitidum* Nutt., *latipes* Hook., *lasiocarpum* Nutt., *alyssoides* A. Gray, and *perfoliatum* L.).
Tumblemustard (*Sisymbrium altissimum* L.).

The seeds of the winter-spring hosts usually germinate in the fall, but occasionally some germination occurs in the spring. The fall-germinating seeds complete their growth the following spring. The leafhoppers overwinter and produce one or more generations on these weeds before the spring movement takes place, which occurs about the time these weed hosts are maturing and drying. The leafhoppers then move to their summer hosts.

Russian-thistle (*Salsola kali* var. *tenuifolia* Tausch) is the most important summer weed host of the beet leafhopper. Other summer hosts are:

Acanthochiton wrightii Torr.
Bractscale (*Atriplex serenana* A. Nels.).
Chinchweed (*Pectis papposa* Harvey and Gray).
Fogweed (*A. expansa* Wats.).
Smotherweed (*Bassia hyssopifolia* (Pall.) Kuntze).
Tidestromia languinosa (Nutt.) Standl.
Trianthema portulacastrum L.

In California, Idaho, Montana, Nevada, Utah, and Wyoming the recently introduced halogeton (*Halogeton glomeratus* (Bieb.) C. A. Mey), which is poisonous to livestock, is also a summer host. Recently Siberian mustard (*Chorispora tenella* (Pall.) DC.) and kochia (*Kochia scoparia* (L.) Schrad.) have invaded the breeding areas of southwestern Idaho. These invasions emphasize the fact that the host-plant complex for both the beet leafhopper and the curly top is constantly changing.

In the breeding areas from Washington to central Utah the important spring and summer weed hosts of the beet leafhopper, except green tansymustard, are foreign plants that have become established

on abandoned, waste, and deteriorated rangelands. In the more southern areas filaree and Russian-thistle are the only important spring and summer weed hosts that are of foreign origin.

In addition to the principal weed hosts mentioned, the beet leafhopper has a wide range of other hosts, including ornamental and other cultivated plants, as well as weeds. These hosts are found in at least 25 families. They can be divided into two classes—feeding hosts, such as beans, cantaloups, and tomatoes, and breeding hosts, such as beets, spinach, and various weeds. The breeding hosts vary considerably in their suitability for the production of leafhoppers. Some germinate early in the spring, and under adverse conditions will mature before the leafhoppers reach the winged stage: in such cases the nymphs must move to nearby hosts or die. Hosts that are otherwise suitable for leafhopper reproduction are of minor importance because of the habitat in which they grow. Some of the common weed hosts growing in fields and waste areas are lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), redscale (*Atriplex rosea* L.), Frenchweed (*Thlaspi arvense* L.), and falseflax (*Camelina microcarpa* Andrez.).

BREEDING AREAS

The host plants usually occur in patches scattered over definite areas. When the weather is favorable, such areas are very productive of leafhoppers. Although it is difficult to trace the flights of such tiny insects, and much remains unknown about their movements, it is known, in a general way, that leafhoppers from any one breeding area infest the same cultivated areas year after year. The six major breeding areas, together with the areas in which sugar beets are grown in the West, and the general routes followed by the leafhoppers in their spring migrations are shown in figure 5. Many other small breeding areas have been found, which are often of great local importance.

The six major breeding areas seem to be nearly independent of each other. All except the one along the Rio Grande in Texas and New Mexico (Area 3) are west of the Continental Divide. All are in arid or semiarid country, where the mean annual rainfall is not more than 12 inches and practically all agriculture depends upon irrigation. In all except the lower Colorado River (Area 2) and Rio Grande areas the summers are very dry and the heaviest rainfall is during the winter or spring. In southern Arizona and New Mexico and in southwestern Texas there is an appreciable winter rainfall and another rainy period late in the summer. The winter climate varies greatly. In the central Columbia River sections of Oregon and Washington (Area 6), on the lower Snake River plains of Idaho and eastern Oregon (Area 5), and in Colorado, Nevada, and Utah (Area 4), heavy snows and subzero temperatures are not uncommon. In the southern breeding areas the moisture falls as rain, and the winters are short and cool.

Area 1—San Joaquin Valley, California

The important overwintering and spring breeding grounds that affect agriculture in the Sacramento, San Joaquin, and Salinas

Valleys of California lie along the foothills on the west side of the San Joaquin Valley. The important summer breeding grounds are in the valley.

In the San Joaquin Valley practically no rain falls between June 1 and October 1. The heaviest rains come in December, January, and February. The winter is cool, with occasional frost, but the weather is usually warm enough to enable the leafhoppers to remain active. The chief winter host is filaree.

In February and March the overwintered females lay their eggs in various range weeds, especially in pepperweed and desert Indian-wheats. One complete and sometimes a partial second generation are produced in the foothills before the vegetation dries. With the drying of the range plants, the spring broods leave the foothills and migrate into the cultivated areas in the valley bottoms. Here they settle upon their summer hosts, which are Russian-thistle, bractscale, fogweed, and other plants, including sugar beets. These migrating leafhoppers transmit the virus of curly top disease, and at this time (April and early May) the damage to cultivated crops begins.

Several generations of leafhoppers are produced on the summer host plants, and the leafhoppers remain in the lowlands until the weed hosts mature or the crops are harvested. During October and November they drift back into the foothills of the Coast Range. At this time, before the fall rains have begun, few annual host plants are present. Therefore, the leafhoppers congregate upon what green vegetation is available, principally patches of perennial plants in the bottom and on the sides of dry washes and on the valley floor.

For a short period the leafhoppers may be forced to feed upon these plants, which include cattle saltbrush, spring saltbrush, and California scalybroom. They remain on these holdover hosts until the rains cause the winter annual host plants to germinate. Many of the leafhoppers die if the rains are greatly delayed. With the coming of the winter rains they leave the holdover plants and feed on the newly germinated annuals.

More than 400,000 acres of curly-top-susceptible crops are grown in the San Joaquin, Sacramento, and Salinas Valleys. The major susceptible crops are sugar beets, tomatoes, melons, spinach, flax, and beans. The growers of these crops suffer serious losses during years of severe exposure.

Area 2—Lower Colorado River

Breeding grounds along the lower Colorado River lie in southwestern Arizona, southeastern California, southern Nevada, and southern Utah. These are the largest spring breeding areas in the United States, and leafhoppers moving from them affect agriculture in Arizona, Utah, Nevada, western Colorado, and northwestern New Mexico. The summers are long and hot, and the winters short and cool. There are rains in December, January, and February, and also in July and August. The total rainfall is very light.

In Arizona and southeastern California the beet leafhopper overwinters on such annuals as pepperweed, patata, desert Indian-wheat, and filaree. The first spring generation usually moves northward late in April, infesting Russian-thistle and cultivated crops in these States, and Russian-thistle in the Escalante Desert and Wolf Hole

sections of Utah. These movements may extend as far north as the Great Salt Lake and the Grand Valley of Colorado. The number of leafhoppers reaching these areas is usually too small to do much direct damage to agricultural crops, but they reinforce the overwintered leafhoppers in the local spring breeding grounds.

The second spring generation moves northward in late May and early June. Their numbers may be increased en route by spring-generation adults produced in local breeding grounds. This northward movement is the principal source of leafhopper infestation and curly top disease in western Colorado and eastern Utah. Nearly all the leafhoppers have left the desert areas of southern Arizona and southeastern California by the early part of June, and it is not until late in July, when the summer rains occur, that the breeding grounds of southern Arizona are repopulated by leafhoppers moving from pepperweed that grows southeast of the chief breeding area. Summer rains cause the germination of chinchweed, *Tidestromia languinosa*, *Trianthema portulacastrum*, and Russian-thistle, which serve as summer hosts, and one or two generations of leafhoppers may be produced upon these plants before they mature and dry in the fall.

The Escalante Desert and the Wolf Hole sections are considerably higher than the breeding grounds to the south. Leafhoppers breed here during the summer and move southward in September and October. If the late-fall rains do not bring about germination of the winter hosts before the summer hosts die, the leafhoppers shift to holdover hosts, as in other areas.

Sugar and garden beets are grown in the Salt River Valley of Arizona, and sugar beets for seed in the St. George section of Utah, and they may be infected in the fall with curly top. Tomatoes, melons, and squash are injured by curly top in the spring.

In the Moapa Valley of Nevada thousands of tomato plants are grown in the field for sets. These small plants are infected with curly top during the spring movement of the leafhoppers. Since the symptoms of the disease do not show up for some time, plants may be sold to growers for transplanting without evidence that they are diseased.

Area 3—Rio Grande Area of New Mexico and Texas

The breeding grounds of New Mexico and Texas, located in the Rio Grande Valley and adjacent areas in south-central New Mexico and southwestern Texas are the only ones of any size east of the Continental Divide.[1] Here there is both summer and winter rainfall. Throughout the warmer months the beet leafhoppers breed upon a perennial pepperweed. In August and September most of them leave the pepperweed and breed upon plants similar to those in the Arizona area. The fall rains stimulate new growth in the old pepperweed crowns, and seedlings sprout. The leafhoppers then return to this plant.

The leafhoppers remain in this area throughout the year. Two spring generations are produced on the pepperweed, and in May and June surplus populations move northward, where they affect suscep-

[1] Limited studies in February and March 1954 indicate that Area 3, shown in figure 5, now extends into northwestern portions of Texas and Oklahoma and eastward in those States to about the 98th parallel.

tible crops east of the Continental Divide in New Mexico, western Texas, southeastern Colorado, and southwestern Kansas. Agricultural areas as far north as Pueblo, Colo., Garden City, Kans., and Amarillo, Tex., may be infected with curly top by leafhoppers from this breeding area. In the fall leafhoppers from this area drift southward into nearby agricultural areas, where they infest fall crops. Farther down the Rio Grande in the Big Bend there is another, smaller breeding ground which has a host-plant complex similar to that of southern Arizona. In the spring this breeding ground is apparently of small importance, but fall populations drift to the southeast into agricultural districts.

Sugar beets grown in eastern New Mexico and in the Arkansas River Valley in Colorado and Kansas are occasionally infected with curly top. Tomatoes, beans, spinach, and melons are also infected in spring flights. In fall flights leafhoppers affect beets grown for seed, as well as spinach, in the Rio Grande Valley, sometimes doing severe damage to spinach in the winter garden area near Del Rio, Tex.

Area 4—Scattered Breeding Grounds in Colorado, Nevada, and Utah

The breeding grounds of western Colorado, northern Nevada, and northern Utah are small and scattered. The most important ones are within the Great Salt Lake Basin and near the Carson and Humboldt Sinks and Pyramid Lake. The winters are severe, with a snow cover most of the season. The summers are warm and dry. The heaviest rains come in the spring and fall, but light rains may fall in any month.

In northern Utah the leafhoppers overwinter on filaree, blistercress, and African mustard. In the Carson and Humboldt Sinks and the Pyramid Lake section they overwinter on tansymustard and pepperweed. A generation is produced on these annual weeds before they mature and dry in the spring. This spring generation is reinforced by the progeny of migrants from the southern breeding grounds. When the spring generation has matured the leafhoppers move to their summer hosts. This movement occurs at about the same time as the second flight of leafhoppers from the lower Colorado River area. Two summer generations are produced on Russian-thistle, smotherweed, kochia, and sugar beets. When the weed hosts have matured and dried and the beets have been harvested, the leafhoppers move to their winter hosts, if sufficient rains have caused them to germinate. If not, they are forced to move to sagebrush and rabbitbrush, the holdover hosts, for a short period.

The curly-top-susceptible crops grown in this area are sugar beets, tomatoes, beans, and melons. Tomatoes are grown commercially in the Grand Valley of Colorado and northern Utah, and in years of high leafhopper infestation losses are heavy. Even the yields of curly-top-resistant varieties of sugar beets are adversely affected in years of severe exposure.

Area 5—Lower Snake River Plains of Idaho and Oregon

The breeding grounds in Idaho and eastern Oregon lie on the Snake River plains at elevations below 4,500 feet. There is some summer reproduction above this elevation, but these areas are generally popu-

lated each spring. The spring movement progresses eastward. The temperature and rainfall are similar to those in northern Utah and Nevada. The winters are cold, with snow during the subzero period, and the summers are warm and dry. The heaviest rains come in the spring and fall, and light rains in the summer.

The winter vegetation normally germinates in October and November. However, in some years no succulent vegetation is available before winter, and the leafhoppers are forced to feed on big sagebrush. The spring breeding hosts are flixweed, green tansymustard, perfoliate pepperweed, and tumblemustard. These plants mature and dry about the time the spring-generation leafhoppers reach the adult stage. When weather conditions are favorable for flight, the leafhoppers move to Russian-thistle, smotherweed, and sugar beets, where two more generations are produced. In the fall they may move directly to their winter and spring hosts, unless they are forced to spend some time on big sagebrush and rabbitbrush.

The climate and soil are suitable for the production of sugar beets, beans, tomatoes, melons, spinach, and zinnia seed, but curly top restricts tomatoes, spinach, and zinnias to local gardens. In years of heavy curly-top exposure, practically all tomatoes and spinach grown for local markets are so seriously damaged that they are a total loss. Fresh fruits and vegetables have to be shipped in to supply the local demand.

Area 6—Columbia River Sections of Oregon and Washington

The breeding grounds of Oregon and Washington lie in the dry sagebrush plains of the Columbia River Basin from the Grand Coulee to central Oregon (fig. 5). Leafhoppers from this area infest beans, sugar beets, tomatoes, and other susceptible crops in the Yakima and Walla Walla Valleys and other smaller irrigated sections. In some seasons they are blown down the Columbia River gorge into the Willamette Valley. The area has cold, wet winters and hot, dry summers. The fall rains usually begin in October and the winter vegetation germinates before the middle of November. The chief summer hosts of the beet leafhopper are Russian-thistle and smotherweed, which are usually dry in October. Therefore, for a short period the leafhoppers may be forced to feed upon sagebrush and rabbitbrush, which are the holdover hosts of the area. The overwintering and spring host plants are filaree, tumblemustard, flixweed, green tansymustard, and perfoliate pepperweed.

The leafhoppers are usually inactive during most of December and January. In the spring eggs are laid in the spring-weed hosts. When these plants mature and dry, the leafhoppers move to their summer hosts, where two more generations are produced. With the drying of Russian-thistle and the harvesting of sugar beets, the leafhoppers move back to holdover hosts and winter annuals, completing the cycle.

This area is well suited for the production of beans, sugar beets, tomatoes, melons, and squash. However, all attempts to grow beans failed until the introduction of field-bean varieties resistant to curly top, which are now extensively grown. Snap beans cannot be successfully grown for seed on account of curly top. Few tomatoes are grown commercially for the same reason. Susceptible varieties of

squash and melons are damaged in years of leafhopper outbreaks. Since this is one of the important beet-leafhopper breeding areas, curly top will be the limiting factor in growing susceptible crops in the Grand Coulee irrigation area.

Other Breeding Areas

Areas north and east of those outlined above are occasionally infested with beet leafhoppers. The most important are the Arkansas River Valley of Colorado, the Big Horn Basin of Wyoming, and that part of Montana near Billings. These areas are infested at times during the spring apparently by long-range migrations of leafhoppers from one of the major breeding areas. The infestations last from one to several years, and generally die out because of unfavorable weather. Host plants in these areas are favorable for the establishment and maintenance of beet leafhopper populations and the virus of curly top. In the Big Horn Basin of Wyoming an infestation started in 1941 still persists in certain localities. Russian-thistle, kochia, smotherweed, and halogeton are the summer hosts. The important overwintering and spring hosts are flixweed, tansymustard, perfoliate pepperweed, tumblemustard, desert Indian-wheat, and patata.

SUMMARY

The beet leafhopper is a serious menace to sugar beets, beans, tomatoes, and other crops in the western part of the United States. It rarely becomes sufficiently abundant to cause great damage by its feeding, but it transmits a virus that causes curly top, a destructive disease which attacks many important agricultural crops and ornamental plants.

The leafhopper breeds in vast areas of weeds that have grown up on abandoned farmlands and deteriorated range. The important overwintering and spring hosts are filaree, flixweed, tansymustard, pepperweeds, tumblemustard, desert Indian-wheats, and patata, which are rather short lived. When these plants mature and dry, the leafhoppers move to summer hosts, chiefly Russian-thistle. They travel with the wind and infest practically all host plants in their path. It is in the course of these movements that cultivated crops are infected with curly top.

Because the leafhopper moves long distances and causes damage by transmitting curly top virus rather than by mass feeding, it cannot be controlled by ordinary chemical or cultural methods. Control can be attained, however, through long-range programs, including spraying with herbicides, to eliminate leafhopper breeding areas. Spraying breeding grounds where female leafhoppers concentrate will greatly lessen leafhopper populations. After the leafhopper moves into susceptible crops, there is no entirely satisfactory control. Planting of resistant varieties, proper timing of planting dates, and treating with insecticides will aid in reducing curly top damage.

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